Egypt. J. Plant Breed. 20(5):773 – 795 (2016)

THE RELATIONSHIP BETWEEN YIELD AND EACH OF ITS ATTRIBUTES AND SOME PHYSIOLOGICAL TRAITS IN GRAIN SORGHUM UNDER WELL-WATERING AND WATER STRESS CONDITIONS

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ABSTRACT

It is desirable for sorghum breeder to know the extent of relationship between yield and each of morphological and physiological traits affecting it which facilitate breeder in selecting plants of desirable traits, especially under drought stress conditions. Therefore, this work was conducted at two locations represent clay and sandy soils of the Experimental Farms of Faculty of Agriculture, Assiut University, Assiut, Egypt, during the two summer seasons 2014 and 2015 under well-watering (WW) and water stress (DS) conditions. Three statistical procedures, i.e. simple correlation coefficient, the path coefficient analysis and the stepwise regression analysis were performed to determine the functional relationships between grain yield (GY) and each of its attributes and some physiological traits of 43 grain sorghum genotypes under both treatments. Results revealed highly significant differences among genotypes for all studied traits under both conditions. Panicle weight (PWG) had the highest positive correlation with grain yield of sorghum genotypes under both treatments followed by threshing percentage (TH%) and seed index, reflecting these traits are the most contributed to yield. Path analysis showed that PWG and TH% had positive and direct effect on GY, while chlorophyll content (CC), excised leaf water loss (ELWL) and stay green were the most important physiological traits under DS conditions. In addition, panicle width and CC showed the highest positive indirect effects on GY. Stepwise regression exhibited that PWG and TH% had the strongest variation in GY under both water regimes. Further, all physiological traits except excised leaf water loss (under WW) showed positive correlation coefficient with GY under both treatments. Also, relative water content was the most important physiological trait followed by flag leaf area under WW conditions, while CC was the most important physiological trait under DS followed by ELWL that contributed high amount of the total variation of grain yield.

Key words: ***Correlation, Path coefficient, Stepwise regressions, Water stress, Sorghum bicolor***

INTRODUCTION

Globally, drought is a serious environmental stress that affects more frequently plant growth and productivity due to the current climate change scenario (Fracasso *et al* 2016). Among world's major cereal crops, Sorghum (*Sorghum bicolor* L. Moench) is the fifth important one and is valued for its grain, stalks and leaves. It is cultivated in Egypt as a summer crop and is concentrated in the middle and upper parts (Hassanein *et al* 2010). In upper Egypt and in semi-arid regions as well, sorghum is often exposed to drought and heat stress, which affect plant growth and grain yield (Prasad *et al* 2008). Sorghum crop shows considerable variation in agronomic, morphological and physiological traits that responsd to selection and are highly influenced by environmental factors (Ezeaku *et al*, 1997). Sorghum improvement to drought tolerance and the other stresses requires from breeders to concentrate on utilization of desirable traits that may aid in superior improved cultivars aiming to surpass the present productivity level (Warkad *et al* 2010). Efforts are currently focused to increase the cultivated area of sorghum in Upper Egypt in newly reclaimed desert land (Ali 2012) by growing high yielding-drought tolerant varieties.

In cereal crops, yield depends on a combination of morphological and physiological attributes that affect the yield directly or indirectly way under well-watered and drought stress conditions. Among these, plant height, panicle length, panicle width, panicle weight, threshing percentage, grain number and 1000-grain weight (Warkad *et al* 2010; Ghasemi *et al* 2012; Tolk *et al* 2013; Khaled *et al* 2014). In addition, excised-leaf water loss (Wang and Clarke, 1993, Ahmad *et al* 2009); relative water content (Rad *et al* 2013, Ahmad *et al* 2009); stay green (Subudhi *et al* 2000, Borrell *et al* 2014); chlorophyll content (Brito *et al* 2011, Asadi *et al* 2015); flag leaf area (Asadi *et al* 2015) as examples of the physiological traits and have been measured to assess drought tolerance in sorghum.

Raising grain yield potential is one of the major objectives in sorghum improvement programmes that can be achieved *via* improving of yield components and physiological traits (Golparvar 2013). However, yield is a quantitative and very complex trait that results of the interaction between various yield attributes; this interaction varies according to the environment, where the plant lives. Several statistical approaches, such as correlation, path coefficient and stepwise regression analysis are very helpful and beneficial in explaining the relationship between yield and contributing factors, especially under different environmental conditions. Further, these tools provide the ability to study the interrelationships and inter-dependence among traits. In multivariate analysis, the plant attributes are referred to as the independent variables, while yield is the dependent variable. Each of the independent variables contributes to the variation in the yield of the genotypes (Abd El-Mohsen 2013). Nature and the magnitude of correlation coefficients of the traits help breeders to determine the selection desirable criteria for simultaneous improvement of various traits along with yield. However, selection based on simple correlation coefficients without considering the interactions among yield and yield attributes may mislead the breeder to reach his main breeding purposes (Del Moral *et al*, 2003). Therefore, path coefficient analysis that was derived from Wright (1921) and described by Dewey and Lu (1959) provides an aid for partitioning of correlation coefficient into direct and indirect effects of different traits on yield and thus helps in assessing the cause-effect relationship as well as effective selection. Also, stepwise multiple linear regression aims to construct a regression equation that includes the independent variables accounting for the majority of the total yield variation. Determination of the relationship between yield and its attributes was reported in several published researches (for instance, Ezeaku and

Mohammed 2006; Jain *et al* 2010; Chavan *et al* 2011 and Abubakar and Bubuche 2013). However, physiological screening of sorghum germplasm for drought response is limited (Rakshit *et al* 2016). Yield and a number of physiological traits have been used to select drought tolerant genotypes (White *et al* 1994). Detailed measurements of the yield components and the physiological traits under a range of water stress conditions are needed to obtain and better understand the possible combination of these traits as independent variables to enhance yield under drought conditions. Therefore, the objective of this study was to increase the understanding of relationships between grain sorghum yield and each of morphological and physiological traits under well-watered and drought stress conditions by studying correlations, stepwise multiple regression and path analysis.

MATERIALS AND METHODS

Experimental sites and plant materials

This investigation was carried out at two locations of the experimental farms of the Faculty of Agriculture, Assiut University, at Assiut, Egypt, during the two summer successive seasons, 2014 and 2015 under two water regimes. The first location was at Agricultural Research Farm, Assiut University (AS location), while the second location was at the newly reclaimed area at the Experimental Station of the Faculty of Agriculture, Al-Wadi Al-Assyouti Farm (WAD location), Assiut University (25 km South East of Assiut). Details of the soil physical and chemical properties of the two locations were described in Sayed and Mahdy (2016) and Sayed and Bedawy (2016).

30 F_1 grain sorghum crosses formed by crossing six inbred lines (cytoplasmic male sterile lines) to five testers in a line × tester mating design in the summer season of 2013 in addition to two standard checks (Hybrid 305 and Dorado) for comparison were used in this study. The female lines ICSA.11, ICSA.329, ICSA536, ICSA598, ICSA625 and ATXA629 and male lines ICSR102, ICSR59, ICSR628, ICSR89013 and ICSR 89034 were obtained from India (International Crop Research Institute for Semi-Arid Tropics, ICRISAT) except one female line (ATXA629), which was obtained from Texas A&M University, College Station, TX, U.S.A.

Experimental design and water regimes

Two separate field treatments (well-watered and drought stress treatments) were performed at each location. The experimental design was a strip plot design in a randomized complete block arrangement with three replications. Water regimes were allocated to the main plots and genotypes to subplots. Each genotype was placed in a one row plot of 3 m long and 0.6 m apart with 0.2 m between plants. Trial was hand planted with 3-4 seeds per hill, which was later thinned to two plants per hill. Planting was done in the two summer successive seasons at the 17th and 18th of June, 2014 and in

16th and 17th of June, 2015, in the first and second locations, respectively. Standard cultural practices for optimum sorghum production were carried out at each location. In the first location, to obtain well-watered conditions (WW), entries were watered using surface irrigation each 14 days and as recommended for optimum sorghum production, while to obtain drought stress conditions (DS), the third and the fifth irrigations were skipped. In the second location, in both treatments drip irrigation was used and plants were watered each 3 days. In WW treatments, plants were irrigated for 2 hours while in DS treatment, plants were irrigated for 1 hour (drought stress conditions started after 30 days from sowing and continued until fully ripening).

Recording of observations

Grain yield/plant (GY/P; g) and its attributes were recorded on five tagged guarded plants from each plot. The yield attributes were; plant height (PH; cm), panicle length (PL; cm), panicle width (PW; cm), panicle weight (PWG; g), threshing percentage (TH %) and seed index (SI; g) whereas days to 50% blooming (DB) data were recorded on whole plot basis. In addition, five physiological traits related to drought tolerance were measured in this study, namely relative water content (Barrs 1968); excised-leaf water loss (Clarke 1987); chlorophyll content (Xu *et al* 2000); stay green (Wanous *et al* 1991) and flag leaf area (FLA) (Montgomery 1911). Details of the measurements of the yield, yield attributes and the physiological traits of were described in (Sayed and Mahdy 2016 and Sayed and Bedawy 2016).

Statistical analysis and procedures

The combined analysis of variance as outlined by Gomez and Gomez (1984) was computed for well-watered and drought stress treatments after carrying out the homogeneity of variances using Bartlett test using SAS software (v 9.2, 2008). Phenotypic correlations among yield attributes and the physiological traits along with grain yield were determined under well-watered and drought stress conditions separately across years and locations using Pearson's correlation test using SAS software. Path coefficient analysis was performed under the two water regimes and between yield and each of its attributes and the physiological traits separately using Analysis of Moment Structures software (AMOS v. 5; Arbuckle 2005). The direct and indirect effects of influential variables on grain yield were calculated according to proposed method of Dewey and Lu (1959). Stepwise linear regression according to Draper and Smith (1966) was computed using SAS software to determine the appropriate variables significantly contributed to total variation in yield and the relative contribution was calculated as (R^2). In path coefficient and stepwise regression analyses, grain yield was examined as the dependent variable versus other traits as independent variables.

RESULTS AND DISCUSSION

Analysis of variance of the studied traits under both treatments

Data in Tables (1 and 2) show the combined analysis of variance and some summary statistics for grain yield, its attributes and some physiological traits related to drought tolerance of 43 sorghum genotypes under well-watered and drought stress conditions, respectively across two locations and across two seasons. ANOVA revealed highly significant differences between seasons, between both locations and for their interaction for the majority of the investigated traits, reflecting the impact of the environmental conditions on the expression of the investigated traits of the genotypes. Likewise, results showed highly significant differences among genotypes for all studied traits under well-watered and drought stress conditions, indicating the existence of sufficient variability among genotypes. In addition, the interaction of genotypes with years was significant for all studied traits under both treatments, while the interaction of genotypes with locations and 2nd order interaction were insignificant for all studied traits, except few cases under both treatments. From the combined analysis, all of investigated traits showed a wide range of variability under both treatments. For instants, grain yield per plant (GY/P) ranged between 21.1 and 59.7 g under well-watered conditions and between 13.8 and 53.1 g under drought stress conditions. Excised leaf water loss (ELWL), as an example for the physiological traits, ranged from 49 to 79.9% under well-watered conditions and from 49.6 to 85.4% under drought stress conditions. Therefore, the presence of such range of variations of the traits indicated that the presence of large amount of genetic variation among tested lines, hybrids and check cultivars, which is the source of variable genetic material. The coefficient of variability (C.V.) of the investigated traits (Tables 1 and 2) was higher under drought stress conditions than under well-watered conditions, this may be due to the different responses of the genotypes to drought stress. Since, days to 50% heading exhibited the minimum percentage of coefficient of variation (2.6%) under both treatments, while flag leaf area showed the maximum percentage of coefficient of variation (27 to 29.1%) under well-watered and drought stress conditions, respectively. Tariq *et al* (2007) also reported higher phenotypic variance for grain yield among the sorghum varieties. Also, Tag El-Din *et al* (2012) and El-Naim *et al* (2012) reported that highly significant differences were obtained among grain sorghum genotypes for yield and its attributes. Amare *et al* (2015) studied the variability for yield and yield related traits of sorghum varieties in Ethiopia and found a wide range of variation among the varieties across locations for yield and its attributes this variation confirmed by high values of phenotypic and genotypic variation for the investigated traits.

Table 1. Combined analysis of variance and summary of statistics for grain yield, yield attributes and physiological traits under well-watered conditions across two locations and across two seasons.

SOV	df	Mean squares							
		Grain yield and its attributes							
		GY/P	50% HD	PH	PL	PW	PWG	TH%	SI
Year (Y)	1	5596.9**	427.8**	595.9	193.0**	14.5	937.2	2929.3*	625.2**
Loc. (L)	1	12922**	3448**	73559**	1081.8**	48.1**	18302**	7444.9*	1378.4**
Y*L	1	1798**	128.9**	18919**	84.3*	3.7	168.5	6865.6*	14.8*
Error a	8	150.3	4.5	176.2	10.5	3.0	238.2	59.2	2.4
Genotype	42	1248.5**	128.9**	6432.9**	88.0**	3.3**	2737.7**	226.1**	125.9**
G*Y	42	723.5**	75.9**	1565.7**	28.2**	1.6*	1417.3**	226.0**	56.2**
G*L	42	55.3	0.9	288.5**	2.1**	0.4	99.3	5.9	4.9
G*Y*L	42	41.3	1.0	188.0**	1.4	0.4	74.7	5.8	3.2
Error b	336	72.13	2.8	106.4	5.3	1.0	157.9	37.1	6.1
R^2		0.81	0.93	0.92	0.78	0.50	0.79	0.74	0.83
C.V.		20.6	2.6	7.7	8.7	16.6	18.3	10.6	9.7
Mean		41.2	63.1	133.2	26.5	5.9	68.6	57.2	25.5
Minimum		21.1	54.6	92.0	19.2	4.6	38.3	47.7	18.1
Maximum		59.7	74.3	180.5	32.1	7.2	96.8	65.6	32.2

SOV	df	Mean squares				
		Physiological traits				
		RWC	ELWL	CC	Stg	FLA
Year (Y)	1	2698.5**	16594**	2353.6**	115.0**	8033.0
Loc. (L)	1	19235**	1412**	4161**	59.7*	200100*
Y*L	1	4888.4**	2584.1*	110.4*	1.1	36232.0
Error a	8	27.4	119.1	18.1	8.3	11151.0
Genotype	42	115.1	499.8**	45.6**	6.7**	8893.6**
G*Y	42	116.5	189.0**	35.4**	1.3	6620.6**
G*L	42	9.9	144.0**	16.9**	1.7*	904.3
G*Y*L	42	6.7	158.1**	16.5	1.3	985.4
Error b	336	29.6	44.5	13.3	1.0	2725.4
R^2		0.79	0.80	0.72	0.66	0.53
C.V.		7.5	10.3	7.4	17.5	27.0
Mean		72.1	64.5	49.1	5.8	193.5
Minimum		66.9	49.0	44.9	3.8	138.2
Maximum		78.5	79.9	53.8	7.0	275.0

Where, GY/P=grain yield per plant, 50% HD= days to 50% heading, PH=plant height, PL=panicle length, PW=panicle width, PWG=panicle weight, TH%=threshing percentage, SI=seed index, RWC =relative water content, ELWL=excised leaf water loss, CC=chlorophyll content, Stg=stay green and FLA=flag leaf area. * and **; significant at P values of 0.05 and 0.01, respectively.

Table 2. Combined analysis of variance and summary statistics for grain yield, yield attributes and physiological traits under drought stress conditions across two locations and over two seasons.

SOV	df	Mean squares							
		Grain yield and its attributes							
		GY/P	50% HD	PH	PL	PW	PWG	TH%	SI
Year (Y)	1	43052**	848.3**	7140.7**	18.2	119.2**	44694**	19027*	264.1**
Loc. (L)	1	9063.1**	3354.3**	54587**	850.7**	36.5*	11233**	7872.9*	1452.6**
Y*L	1	2457.1**	95.2**	15691**	75.0	3.3	604.5	7231.6*	21.1*
Error a	8	140.0	4.5	191.6	35.8	1.5	203.8	57.6	2.3
Genotype	42	1072.8**	160.1**	3130.8**	65.7**	3.4**	1980.9**	423.2**	47.8**
G*Y	42	420.8**	81.4**	869.8**	43.1**	2.5**	911.5**	319.4**	29.4**
G*L	42	65.0	0.8	137.5*	1.3	0.1	107.8	7.7	2.6
G*Y*L	42	52.4	1.2	103.0	1.4	0.1	92.9	8.4	2.5
Error b	336	68.5	2.8	86.4	7.3	0.5	153.2	43.8	6.8
R^2		0.84	0.93	0.89	0.70	0.73	0.78	0.81	0.69
C.V.		25.2	2.6	8.4	11.8	13.0	23.2	11.6	10.6
Mean		32.8	63.8	110.8	23.0	5.3	53.3	57.0	24.7
Minimum		13.8	57.2	74.6	17.3	4.3	30.7	40.5	21.1
Maximum		53.1	77.4	145.5	28.1	6.3	80.6	65.6	28.4

SOV	df	Mean squares				
		Physiological traits				
		RWC	ELWL	CC	Stg	FLA
Year (Y)	1	411.4	15343**	4339.7**	98.3**	26150*
Loc. (L)	1	20302**	10670**	3821.9**	46.5*	184295*
Y*L	1	4047.8**	350.6	251.9**	0.4	22662*
Error a	8	123.7	94.0	10.1	8.2	3261.7
Genotype	42	136.9**	692.4**	102.6**	2.6**	7523.6**
G*Y	42	143.8**	135.0*	57.2**	0.8	7439.6**
G*L	42	13.9	102.5	7.8	1.2	572.1
G*Y*L	42	12.9	101.6	7.0	1.0	557.1
Error b	336	39.4	87.3	12.6	1.2	3162.1
R^2		0.74	0.71	0.78	0.52	0.46
C.V.		8.2	12.3	7.7	20.4	29.1
Mean		76.8	75.8	45.9	5.3	193.2
Minimum		65.5	49.6	41.3	4.3	139.0
Maximum		82.6	85.4	57.3	6.5	256.7

Where, GY/P=grain yield per plant, 50% HD= days to 50% heading, PH=plant height, PL=panicle length, PW=panicle width, PWG=panicle weight, TH%=threshing percentage, SI=seed index, RWC =relative water content, ELWL=excised leaf water loss, CC=chlorophyll content, Stg=stay green and FLA=flag leaf area. * and **; significant at P values of 0.05 and 0.01, respectively.

Correlations among studied traits under both treatments

Data in Table (3) shows the correlation coefficients among the studied traits under well-watered and drought stress conditions across years and locations. Under well-watered conditions, the analysis revealed that grain yield/ plant (GY/P) was associated positively and significantly ($P \leq 0.01$) with all studied traits except ELWL, where the correlation (r=-0.07) was negative and insignificant. Among yield attributes, the strongest correlation coefficient with GY/P was obtained by panicle weight (0.94**) followed by threshing percentage (r=0.66**), indicating that these traits are the most contributed to yield/plant. There was a positive and significant correlation between seed index and each of plant height (r=0.51**), panicle length (r=0.31**), panicle width (r=0.14**), panicle weight (r=0.19**) and threshing percentage (r=0.30**). Relative water content (RWC) had the highest correlation coefficient but moderate (r=0.36**) in magnitude with GY/P among the physiological traits followed by flag leaf area (r=0.27**), reflecting the significance of water maintenance in leaf tissues for yield production. It has been observed that RWC was correlated positively and highly significantly with the yield attributes traits, e.g. TH% (r=0.50**) and SI (r=0.27**). Meanwhile, RWC correlated significantly and positively with each of chlorophyll content (r=0.26**), stay green (r=0.28**) and flag leaf area (r=0.29**). However, no evidence of a relationship between RWC and ELWL under well-watered conditions. Chlorophyll content was associated positively and significantly with each of plant height, panicle traits, relative water content and flag leaf area. Under drought stress conditions, the same trend was observed for the association between grain yield and each of its attributes and the physiological traits with an exception that the coefficients were much higher under drought stress than under well-watered conditions. RWC was correlated positively and significantly with GY/P and its attributes except days to 50% heading, the correlation was negative. Also, positive and significant correlation between RWC and CC was observed (r=0.34**). Tag El-Din *et al* (2012) found positive correlation coefficients between grain yield per plant and each of panicle length, panicle width, 1000-kernel weight and leaf area. Khaled *et al* (2014) reported associations between grain yield per plant and its attributes in sorghum. Amare *et al* (2015) found that GY/P showed high positive and significant correlation with panicle weight per plant, leaf area index, plant height and 1000-seed weight. Also, Ezeaku and Mohammed (2006) reported high positive phenotypic correlation coefficients of grain yield with head weight and plant height across two locations. These findings are in partial agreement with the previous mentioned reviews, therefore, the positive correlation of grain yield per plant with studied traits suggested that the possibility of simultaneous improvement of grain yield per plant through indirect selection for these positively correlated traits.

Table 3. Correlation coefficients (r) among grain yield, its attributes and physiological traits under well-watered conditions (above diagonal) and drought stress conditions (below diagonal) across years and locations.

Trait	GY/P	50% HD	PH	PL	PW	PWG	TH%	SI	RWC	ELWL	CC	Stg	FLA
GY/P		0,03	0,34**	0,34**	0,48**	0,94**	0,66**	0,27**	0,36**	-0,07	0,11*	0,15**	0,24**
50% HD	0,06		-0,08	-0,19**	-0,09	-0,02	0,01	-0,10*	-0,22**	0,21**	-0,43**	0,00	-0,19**
PH	0,45**	-0,22**		0,64**	0,13**	0,28**	0,33**	0,51**	0,38**	-0,11*	0,24**	0,34**	0,08
PL	0,32**	-0,41**	0,51**		0,27**	0,36**	0,17**	0,31**	0,24**	-0,21**	0,34**	0,26**	0,16**
PW	0,72**	-0,05	0,21**	0,31**		0,48**	0,32**	0,14**	0,26**	0,01	0,17**	0,01	0,27**
PWG	0,95**	0,03	0,41**	0,36**	0,70**		0,40**	0,19**	0,24**	-0,15**	0,17**	0,07	0,25**
TH%	0,72**	-0,02	0,45**	0,19**	0,55**	0,52**		0,30**	0,50**	-0,03	0,05	0,20**	0,22**
SI	0,26**	-0,06	0,44**	0,17**	0,21**	0,21**	0,30**		0,27**	0,05	0,06	0,29**	0,10*
RWC	0,18**	-0,30**	0,36**	0,23**	0,11*	0,17**	0,21**	0,31**		0,00	0,26**	0,28**	0,29**
ELWL	0,14**	0,13**	-0,12**	-0,16**	0,15**	0,13**	0,07	-0,05	-0,26**		-0,26**	0,16*	-0,13**
CC	0,54**	-0,14**	0,38**	0,27**	0,45**	0,48**	0,48**	0,30**	0,34**	-0,04		-0,04	0,23**
Stg	0,24**	0,11*	0,19**	0,07	0,24**	0,19**	0,25**	0,25**	0,08	0,03	0,26**		0,05
FLA	0,12**	-0,12**	0,16**	0,17**	0,12**	0,16**	0,06	0,26**	0,36**	-0,12	0,17	0,06	

Where, GY/P=grain yield per plant, 50% HD= days to 50% heading, PH=plant height, PL=panicle length, PW=panicle width, PWG=panicle weight, TH%=threshing percentage, SI=seed index, RWC =relative water content, ELWL=excised leaf water loss, CC=chlorophyll content, Stg=stay green and FLA=flag leaf area. * and **; significant at P values of 0.05 and 0.01, respectively.

Stepwise multiple regression

Yield attributes under both treatments

In stepwise regression analysis, grain yield was examined as the dependent variable versus its attributes as independent variables under well-watered and drought stress conditions. The hierarchical stepwise regression involved four steps (models), Table (4) shows the outcome of this regression. In the first step, panicle weight was the most important trait and had the strongest variation in grain yield per plant and accounted for 87.5% of the variance in GY/P. The second step, threshing percentage entered the next after PWG and accounted 9.84% of the variance. The third step, days to 50% heading came the third predictor and accounted for 0.16% of the variance in GY/P. The final step, seed index entered the last and accounted for 0.03% of the variance.

Table 4. Stepwise regression analysis of grain yield/plant and its attributes under well-watered and drought stress conditions across two locations and two years.

Step	Source	Estimat	SE	F value	Pr > F	Partial	Model
Under well-watered conditions							
1	Intercept	-4.93	0.80	37.15	< 0.001		
	Panicle weight (PWG)	0.67	0.01	3597.78	< 0.001	87.50	87.50
2	Intercept	-30.18	0.68	1917.44	< 0.001		
	Panicle weight (PWG)	0.57	0.01	10331.90	< 0.001		
	Threshing % (TH%)	0.55	0.01	1899.99	< 0.001	9.84	97.34
3	Intercept	-38.03	1.52	621.61	< 0.001		
	Days to 50% Heading	0.12	0.02	32.79	< 0.001	0.16	97.50
	Panicle weight (PWG)	0.57	0.01	10994.50	< 0.001		
	Threshing % (PWG)	0.55	0.01	2007.87	< 0.001		
4	Intercept	-39.42	1.61	597.63	< 0.001		
	Days to 50% Heading	0.13	0.02	35.82	< 0.001		
	Panicle weight (PWG)	0.57	0.01	10991.70	< 0.001		
	Threshing % (PWG)	0.55	0.01	1847.56	< 0.001		
	Seed index (SI)	0.06	0.02	6.50	< 0.05	0.03	97.53
Grain yield function equation GY/P=-39.42+0.13 50%DH+0.57 PGW+0.55							
Under drought conditions							
1	Intercept	-6.96	0.59	138.34	< 0.001		
	Panicle weight	0.75	0.01	5259.02	< 0.001	91.10	91.10
2	Intercept	-23.36	0.53	1928.69	< 0.001		
	Panicle weight	0.62	0.01	10018.50	< 0.001		
	Threshing %	0.40	0.01	1417.65	< 0.001	6.54	97.63
3	Intercept	-32.08	1.38	535.64	< 0.001		
	Days to 50% Heading	0.14	0.02	45.82	< 0.001	0.19	97.83
	Panicle weight	0.62	0.01	10811.80	< 0.001		
	Threshing %	0.41	0.01	1561.19	< 0.001		
Grain yield function equation GY/P=-32.08+0.14 50%DH+0.62 PGW+0.41 TH%							

The final model could justify significantly more than 97.5% changes in performance of GY/P (R^2=87.5%) according to the equation:

GY/P; g = -39.42+0.57 PWG + 0.55 TH% + 0.13 50% DH + 0.06 SI

Under drought conditions, the stepwise regression analysis involved three steps. In these steps, three variables namely panicle weight, threshing percentage and days to 50% heading from the previous analysis under well-watered were remained in the final model and seed index was excluded. Panicle weight accounted for 91.10% of the total variance of GY/P followed by threshing percentage which explained 6.54% and finally days to 50% heading accounted 0.19% of the total variance. The independent variables in the final model justified 97.83% of the GY/P variance. Seed index of sorghum grains is affecting by the starch accumulation during flowering and filling stages and drought stress causes reduction in the total accumulation of starch in the grains (Emes *et al* 2003 and Bing *et al* 2013). Saed-Moucheshi *et al* (2013) and Nasri *et al* (2014) reported that spike weight per unit had a positive and significant regression coefficient on grain yield in wheat. Seed index was affected negatively by drought stress and that may be a reason for discarding seed index from the final model. Therefore, the best prediction equation was formulated as follows:

GY/P; g = -32.08+0.62 PWG + 0.41 TH% + 0.14 50% DH

Physiological traits under both treatments

Table (5) shows the accepted physiological traits as independent variables and their relative contributions in relation to grain yield/plant variance under well-watered and drought stress conditions.

Table 5. Stepwise regression analysis models of grain yield/plant and physiological traits under well-watered and drought stress conditions across two locations and two years.

Step	Source	Estimate	SE	F value	Pr > F	Partial R^2	Model R^2
1	**Under well-watered conditions**						
	Intercept	**-2.29**	**5.01**	**0.21^{NS}**	**0.64**		
	Relative water content	**0.60**	**0.07**	**76.97**	**< 0.001**	**13.02**	**13.02**
2	**Intercept**	**-4.68**	**4.99**	**0.88^{NS}**	**0.34**		
	Relative water content	**0.53**	**0.07**	**55.99**	**< 0.001**		
	Flag leaf area (FLA)	**0.04**	**0.01**	**12.85**	**< 0.001**	**2.13**	**15.15**
Grain yield function equation GY/P= -4.68+0.53 RWC+0.04 FLA							
1	**Under drought conditions**						
	Intercept	**-34.26**	**4.63**	**54.56**	**< 0.001**		
	Chlorophyll content (CC)	**1.46**	**0.10**	**212.96**	**< 0.001**	**29.29**	**29.29**
2	**Intercept**	**-5.02**	**5.77**	**75.58**	**< 0.001**		
	Excised leaf water loss	**0.19**	**0.04**	**20.15**	**< 0.001**		
	Chlorophyll content (CC)	**1.48**	**0.09**	**226.36**	**< 0.001**	**2.67**	**31.97**
3	**Intercept**	**-53.49**	**5.87**	**82.95**	**< 0.001**		
	Excised leaf water loss	**0.19**	**0.04**	**19.36**	**< 0.001**		
	Chlorophyll content (CC)	**1.41**	**0.10**	**192.68**	**< 0.001**		
	Stay green (Stg)	**1.31**	**0.49**	**6.98**	**< 0.01**	**0.92**	**32.88**
Grain yield function equation GY/P=-53.49+0.19 ELWL+1.41 SPAD+ 1.31 Stg							

Since, the stepwise regression analysis revealed two models under well-watered and three models under drought conditions. The results showed that relative water content (RWC) and flag leaf area (FLA) R^2 = 15.5%, had justified the maximum of yield changes under well-watered conditions. RWC was the most important physiological trait followed by FLA, hence, the relative contributions in the total variation of grain yield were 13.02% and 2.13%, respectively. The low relative contributions of the

physiological traits may due to these traits are not the components of sorghum yield in fact, but have significant correlation with grain yield. RWC and FLA appeared to be important traits for good production under well-watered conditions. Consequently, based on the final step of stepwise regression analyses, the best prediction equation was formulated as follows:
GY/P; g = -4.68+0.53 RWC + 0.04 FLA

Under drought conditions, the scenario of the physiological traits was changed because of excluding RWC and FLA from the final step of the stepwise regression analysis and adding other physiological traits namely; chlorophyll content (CC), excised leaf water loss (ELWL) and stay green (Stg). However, these traits had justified the maximum of yield changes (R^2 =32.88%). Chlorophyll content was the most important physiological trait under drought conditions and explained 29.29% of the variance in GY/P followed by excised leaf water loss that contributed 2.67% of the total variation of grain yield, and finally stay green was accounted small effect (0.92%) of the total variance of GY/P. Consequently, based on the final step of stepwise regression analyses, the best prediction equation was formulated as follows: Grain yield function equation

GY/P; g=-53.49+0.19 ELWL+1.41 CC+ 1.31 Stg

Saed-Moucheshi *et al* (2013) found that chlorophyll content of the flag leaf and leaf area had a positive and significant regression coefficient on grain yield in wheat. Tolk *et al* (2013) found that panicle mass and leaf area were important traits under drought stress in sorghum.

Yield attributes and the physiological traits together under both treatments

Table (6) shows the final step resulted from stepwise regression analysis between yield as dependent variable and the all studied traits as independent variables under both treatments. It can be seen that seven traits out of twelve were involved in the final model of stepwise regression analysis under well-watered conditions. The model accounted about 97.78% of the variance and panicle weight and threshing percentage explained 87.50 and 9.80% of the variance in GY/P, respectively. Excised leaf water loss explained about 0.30% of the variance in GY/P among physiological traits. Therefore, the best prediction equation was formulated as follows:
GY/P; g=-34,44+0.58 PWG + 0,55 TH% + 0,05 ELWL-0,07 CC -0,05 FLA +0,05 HD + 0,047 SI

Under drought stress conditions, the stepwise analysis showed that the final step included six traits out of twelve, these traits were the most contributed to GY/P with discarding seed index from the final model. Since, panicle weight explained 91.10% of the variance in GY/P followed by threshing percentage which accounted 6.50% of the variance in GY/P. Chlorophyll content explained about 0.20% of the variance in GY/P among physiological traits.

Table 6. The final step (model) of the stepwise regression analysis of grain yield/plant, its attributes and physiological traits under well-watered and drought stress conditions across two locations and two years.

Source	Estimate	SE	F value	Pr > F	Partial R^2	Model R^2
Under well-watered conditions						
Intercept	**-34.44**	**2.31**	**223.29**	**<.0001**		
Panicle weight (PWG)	**0.585**	**0.005**	**12023.10**	**<.0001**	**87,50**	**87,50**
Threshing percentage	**0.553**	**0.012**	**2071.30**	**<.0001**	**9,80**	**97,30**
Excised leaf water loss	**0.055**	**0.009**	**37.21**	**<.0001**	**0,30**	**97,60**
Chlorophyll content	**-0.073**	**0.022**	**11.26**	**0.0009**	**0,10**	**97,70**
Flag leaf area (FLA)	**-0.005**	**0.002**	**6.74**	**0.0097**	**0,04**	**97,74**
Days to 50% heading	**0.058**	**0.023**	**6.30**	**0.0124**	**0,02**	**97,76**
Seed index (SI)	**0.047**	**0.023**	**4.16**	**0.0418**	**0,02**	**97,78**
Grain yield function equation GY/P=-34,44+0.58 PWG+ 0,55 TH%+ 0,05 ELWL+ (-0,07 CC) + (-,005 FLA) +0,05 HD + 0,047 SI						
Under drought stress conditions						
Intercept	**-35.79**	**1.741**	**422.82**	**<.0001**		
Panicle weight (PWG)	**0.614**	**0.006**	**9722.6**	**<.0001**	**91,10**	**91,10**
Threshing percentage	**0.389**	**0.011**	**1370.8**	**<.0001**	**6,50**	**97,60**
Days to 50% heading	**0.139**	**0.02**	**48.28**	**<.0001**	**0,20**	**97,80**
Chlorophyll content	**0.099**	**0.021**	**22.3**	**<.0001**	**0,10**	**97,90**
Flag leaf area (FLA)	**-0.005**	**0.002**	**9.07**	**0.003**	**0,05**	**97,95**
Excised leaf water loss	**0.018**	**0.008**	**5.07**	**0.025**	**0,05**	**98,00**
Grain yield function equation GY/P=-35,79+0.61 PWG+ 0,38 TH% + 0,13 HD + 0,09 CC+ (-0,005 FLA) + 0,018 ELWL						

Panicle mass at maturity provides an integration of growth conditions between the flag leaf stage and the start of grain filling, which is considered to be a part of the critical period for seed number determination (van Oosterom and Hammer 2008) and consequently grain yield. Therefore, the best prediction equation was formulated as follows:

GY/P; g=-35,79+0.61 PWG+ 0,38 TH% + 0,13 HD + 0,09 CC -0,005 FLA + 0,018 ELWL

Path coefficients analysis

For yield attributes

The estimates of direct and indirect effects of the seven yield attributes and five physiological traits on grain yield/plant under well-watered and drought stress conditions are presented in Tables 7 and 8. Path coefficient analysis was performed using coefficient of all the traits with grain yield plant/plant. Results revealed that panicle weight, threshing percentage, days to 50% heading and seed index exerted positive direct effect on grain yield (0.810**, 0.310**, 0.040** and 0.020**, respectively) under well-watered conditions (Table 7).

Table 7. Direct (italic) and indirect effects of seven yield attributes on grain yield/plant in grain sorghum under well-watered and drought stress conditions across two locations and two years.

Independent	50%	PH	Pl	PW	PWG	TH%	SI	Total
Under well-watered conditions								
Days to 50%	_0.040**_	-0.003	-0.007	-0.003	-0.001	0.000	-0.004	0.022
Plant height	0.000	_0.001_	0.001	0.000	0.000	0.000	0.001	0.003
Panicle length	0.002	-0.006	_-0.010_	-0.003	-0.004	-0.002	-0.003	-0.026
Panicle width	0.001	-0.001	-0.003	_-0.010_	-0.005	-0.003	-0.001	-0.023
Panicle weight	-0.015	0.228	0.293	0.388	_0.810**_	0.324	0.157	2.187
Threshing %	0.003	0.114	0.058	0.108	0.136	_0.340**_	0.102	0.862
Seed index	-0.002	0.010	0.006	0.003	0.004	0.006	_0.020**_	0.047
Under drought stress conditions								
Days to 50%	0._040**_	0.000	0.004	0.001	0.020	-0.007	0.001	0.058
Plant height	-0.009	_0.002_	-0.005	-0.002	0.333	0.139	0.001	0.458
Panicle length	-0.016	0.001	_-0.010_	-0.003	0.291	0.059	0.001	0.321
Panicle width	-0.002	0.001	-0.003	_-0.010_	0.569	0.169	0.001	0.723
Panicle weight	0.001	0.001	-0.004	-0.007	_0.810**_	0.162	0.001	0.963
Threshing %	-0.001	0.001	-0.002	-0.005	0.424	_0.310**_	0.001	0.726
Seed index	-0.003	0.001	-0.002	-0.002	0.172	0.094	_0.001_	0.262

*** and **; significant at P values of 0.05 and 0.01, respectively.**

The highest indirect effects on grain yield were observed with panicle width (0.388) followed by threshing percentage (0.324). In addition, panicle weight (2.187) and threshing percentage (0.862) had the highest total effects on grain yield /plant under well-watered conditions. While under drought conditions (Table 7), the same trend was observed, since panicle weight, threshing percentage and days to 50% heading showed positive direct effect on grain yield/plant. Seed index had insignificant effect on grain yield compared to its effect under well-watered conditions. Panicle width (0.569) and threshing percentage (0.424) showed the highest indirect effects on grain yield/plant. Furthermore, panicle weight (0.963), threshing percentage (0.726) and panicle width (0.723) showed the highest total effects on grain yield/plant under drought stress conditions. Yield attributes accounted about 98% of the variance in grain yield/plant under both treatments (Figure 1 A and B). on the other hand, the direct effect of the residual was around 0.15 under both treatments. These findings are in partial agreement with those obtained by (Arunkumar *et al* 2004, Premlatha *et al* 2006, Warkad *et al* 2010, Chavan *et al* 2011, Abubakar and Bubuche 2013 and Khaled *et al* 2014) who found one or more of yield attributes affect directly or indirectly on grain yield in sorghum.

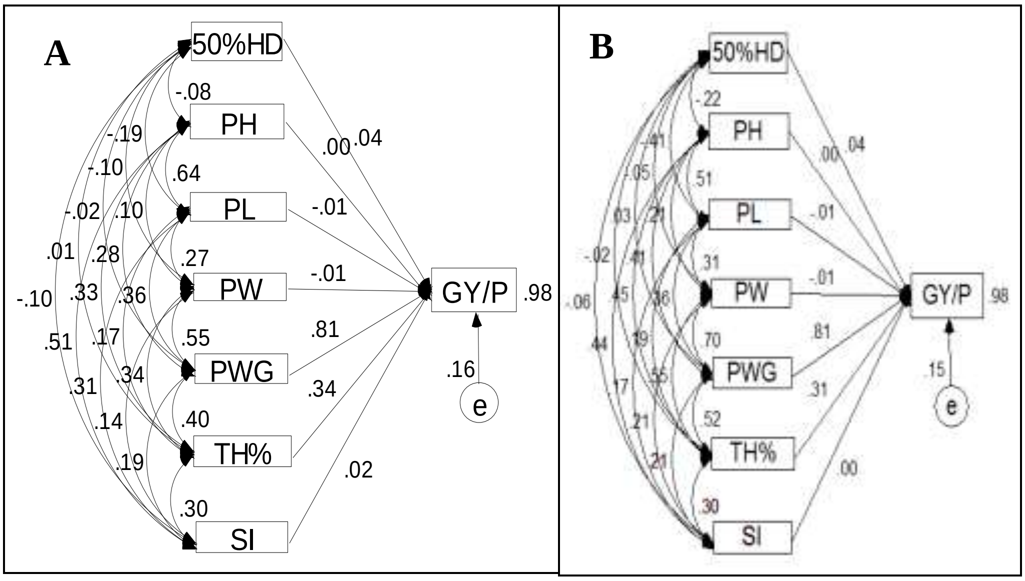

Figure 1. Diagram of path coefficient analysis shows the direct, indirect and residual effects (e) of yield attributes on grain yield per plant under A) well-watered and B) drought stress conditions.

For the physiological traits

Among studied physiological traits, relative water content and flag leaf area had the highest direct effects on grain yield under well-watered conditions (Table 8 and Figure 2 A) and exerted 0.310** and 0.150**, respectively. Both traits gave the highest total effects on grain yield/plant (0.568 and 0.216, respectively). Stay green had the highest indirect effect followed by flag leaf area on grain yield/plant and gave 0.088 for each (Table 7 and Figure 2 A). While under drought stress, chlorophyll content exhibited the highest positive direct effect (0.510**) on grain yield/plant followed by excised leaf water loss (0.170**) then by stay green (0.100**). In addition, chlorophyll content, stay green and relative water content gave 0.546, 0.245 and 0.180 as highest total effects on grain yield/plant under drought conditions, respectively. It was observed that chlorophyll content (0.172) and stay green (0.135) showed the highest positive indirect effect on grain yield/plant under drought conditions (Table 8 and Figure 2 B). The physiological traits under study explained around 16 and 33% of the variance in grain yield/plant under well-watered and drought stress conditions, respectively (Figure 2 A and B). On the other hand, the direct effect of the residual was high for the physiological traits as independent variables under well-watered (0.92) and drought stress (0.82) conditions (Figure 2 A and B), indicating the inadequacy of the trait chosen for the path analysis. Arunah *et al* (2015) stated that leaf area index was the most contributed trait to sorghum yield as an importance photosynthetic ability of a plant as an index of assimilates production for yield.

Table 8. Direct (italic) and indirect effects of five physiological traits on grain yield plant/plant in grain sorghum under well-watered and drought stress conditions over two locations and two years.

Independent variables	RWC	ELWL	CC	Stg	FLA	Total effect
Under well-watered conditions						
Relative water content	***0.310*****	**0.000**	**0.082**	**0.088**	**0.088**	**0.568**
Excised leaf water loss	**0.000**	***-0.070ns***	**0.018**	**-0.011**	**0.009**	**-0.054**
Chlorophyll content	**-0.005**	**0.005**	***-0.020 ns***	**0.001**	**-0.005**	**-0.024**
Stay green	**0.017**	**0.010**	**-0.002**	***0.060 ns***	**0.003**	**0.088**
Flag leaf area	**0.043**	**-0.019**	**0.034**	**0.008**	***0.150*****	**0.216**
Under drought stress conditions						
Relative water content	***0.030 ns***	**-0.044**	**0.172**	**0.008**	**0.014**	**0.180**
Excised leaf water loss	**-0.008**	***0.170*****	**-0.022**	**0.003**	**-0.005**	**0.138**
Chlorophyll content	**0.010**	**-0.007**	***0.510*****	**0.026**	**0.007**	**0.546**
Stay green	**0.002**	**0.005**	**0.135**	***0.100*****	**0.002**	**0.245**
Flag leaf area	**0.011**	**-0.020**	**0.086**	**0.006**	***0.040 ns***	**0.123**

*** and **; significant at P values of 0.05 and 0.01, respectively.**

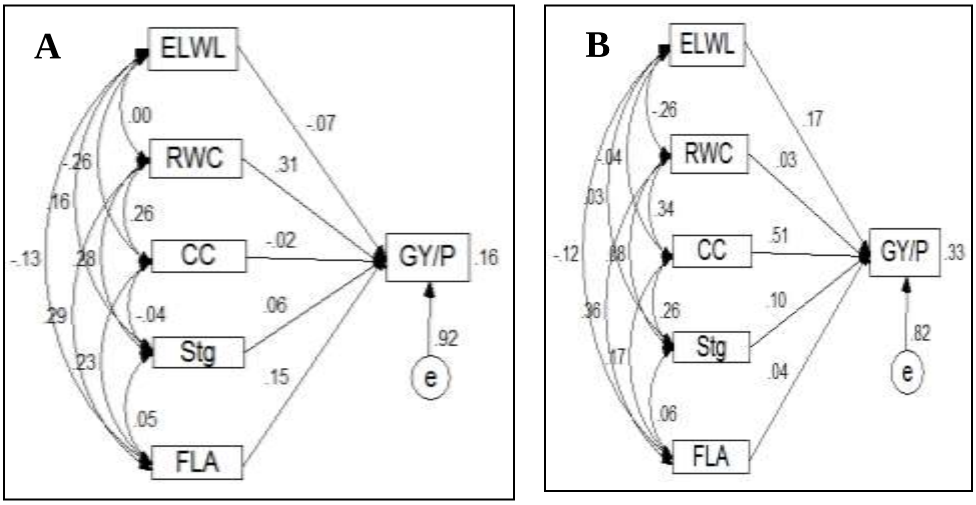

Figure 2. Diagram of path coefficient analysis shows the direct, indirect and residual effects (e) of the physiological traits on grain yield per plant under A) well-watered and B) drought stress conditions.

Saed-Moucheshi *et al* (2013) reported positive indirect effect of chlorophyll content and leaf area on on grain yield in wheat. Ali *et al* (2009) found that flag leaf area exhibited strong positive relationship with grain yield and plays a vital role in drought tolerance.

For yield attributes and the physiological traits together under both treatments

The direct and indirect effects of the yield attributes and the physiological traits to grain yield under well-watered and drought stress conditions are presented in Table (9). Results revealed that panicle weight, threshing percentage, days to 50% heading and excised leaf water loss exerted significant and positive direct effect on grain yield (0.819**, 0.336**, 0.019** and 0.043**, respectively), while panicle width, chlorophyll content and flag leaf area showed significant and negative direct effect on grain yield/plant under well-watered conditions. The highest indirect effects on grain yield were observed with panicle width (0.575) followed by threshing percentage (0.328). While under drought conditions, panicle weight, threshing percentage, days to 50% heading and chlorophyll content exerted significant and positive direct effect on grain yield (0.799**, 0.294**, 0.040** and 0.038**, respectively), while panicle width and flag leaf area showed significant and negative direct effect on grain yield/plant. The highest indirect effects on grain yield were observed with threshing percentage (0.418) followed by chlorophyll content (0.382). These results are in partial agreement with those reported by Ali *et al* (2009); Tolk *et al* (2013) and Saed-Moucheshi *et al* (2013).

Grain yield of sorghum is the integration of various variables that affect plant growth throughout the growing period. Many efforts have been achieved to develop proper models that can predict grain yield and distinguish the ideal- and high yielding crop plants (Saed-Moucheshi *et al* 2013). The knowledge of association and relationship between grain yield and its components under water stress conditions would improve the efficiency of breeding programs by identifying appropriate indices to select sorghum genotypes. The results of the present study showed highly significant differences among genotypes for all studied traits under well-watered and drought stress conditions. However, the existence of sufficient variability among genotypes may help sorghum breeders in investigating and understanding the association between yield and the influencing variables under both water regimes. Also, results showed that panicle weight had the highest positive correlation with grain yield of sorghum genotypes under both treatments followed by threshing percentage and seed index, reflecting these traits are the most contributed to yield. Panicle weight and threshing percentage had the strongest variation in grain yield per plant and accounted 87.5 and 9.84% of the variance in GY/P under well-watered conditions, respectively. While they explained 91.10 and 6.54% of the GY/P variance under drought stress conditions, respectively. On other hand, all physiological traits except excised leaf water loss (under well-watered conditions) showed positive correlation coefficient with GY/P.

Table 9. Direct (italic) and indirect effects of yield attributes and physiological traits on grain yield plant/plant in grain sorghum under well-watered and drought stress conditions over two locations and two years.

Independent variables	HD	PH	PL	PW	PWG	TH	SI	RWC	ELWL	CC	Stg	FLA
Under well-watered conditions												
Days to 50% heading	0.019 *	-0.001	-0.004	-0.002	0.000	0.000	-0.002	-0.004	0.004	-0.008	0.000	-0.004
Plant height	-0.012	-0.003ns	-0.002	0.000	-0.001	-0.001	-0.001	-0.001	0.000	-0.001	-0.001	0.000
Panicle length	-0.032	0.111	0.007ns	0.002	0.003	0.001	0.002	0.002	-0.001	0.002	0.002	0.001
Panicle width	-0.011	0.016	0.033	-0.017 *	0.575	0.281	0.137	0.169	-0.104	0.119	0.050	0.173
Panicle weight	-0.003	0.046	0.059	0.078	0.819 **	0.328	0.159	0.197	-0.121	0.139	0.059	0.202
Threshing percentage	0.001	0.019	0.010	0.018	0.022	0.336 **	0.101	0.169	-0.009	0.017	0.068	0.073
Seed index	-0.024	0.130	0.080	0.037	0.050	0.077	0.011 ns	0.003	0.001	0.001	0.003	0.001
Relative water content	-0.077	0.135	0.086	0.093	0.086	0.180	0.095	0.010 ns	0.000	0.003	0.003	0.003
Excised leaf water loss	-0.024	0.013	0.025	-0.001	0.017	0.003	-0.006	0.000	0.043 **	-0.011	0.007	-0.006
Chlorophyll content	-0.073	0.041	0.058	0.029	0.029	0.009	0.010	0.045	-0.044	-0.027 **	0.001	-0.006
Stay green	0.000	0.020	0.016	0.001	0.004	0.012	0.017	0.017	0.010	-0.002	0.005 ns	0.000
Flag leaf area	0.003	-0.001	-0.003	-0.005	-0.004	-0.004	-0.002	-0.005	0.002	-0.004	-0.001	-0.017 *
Under drought stress conditions												
Days to 50% heading	0.040 **	0.000	0.001	0.001	0.001	-0.007	0.000	0.001	0.002	-0.005	0.001	0.002
Plant height	-0.009	-0.006 ns	-0.001	-0.004	-0.002	0.132	0.002	-0.002	-0.002	0.014	0.001	-0.003
Panicle length	-0.016	-0.003	-0.003 ns	-0.006	-0.001	0.056	0.001	-0.001	-0.002	0.010	0.000	-0.003
Panicle width	-0.002	-0.001	-0.001	-0.021 *	-0.012	0.160	0.001	0.000	0.002	0.017	0.001	-0.002
Panicle weight	0.001	-0.002	-0.001	-0.015	0.799 **	0.154	0.001	-0.001	0.002	0.018	0.001	-0.003
Threshing percentage	-0.001	-0.003	0.000	-0.011	0.418	0.294 **	0.002	-0.001	0.001	0.018	0.002	-0.001
Seed index	-0.003	-0.002	0.000	-0.004	0.170	0.089	0.005 ns	-0.001	-0.001	0.011	0.001	-0.005
Relative water content	-0.012	-0.002	-0.001	-0.002	0.133	0.062	0.002	-0.004 ns	-0.004	0.013	0.000	-0.007
Excised leaf water loss	0.005	0.001	0.000	-0.003	0.100	0.020	0.000	0.001	0.015 *	-0.002	0.000	0.002
Chlorophyll content	-0.006	-0.002	-0.001	-0.009	0.382	0.141	0.001	-0.001	-0.001	0.038 **	0.002	-0.003
Stay green	0.004	-0.001	0.000	-0.005	0.153	0.075	0.001	0.000	0.000	0.010	0.006 ns	-0.001
Flag leaf area	-0.005	-0.001	0.000	-0.003	0.130	0.016	0.001	-0.002	-0.002	0.006	0.000	-0.019 **

*** and **; significant at P values of 0.05 and 0.01, respectively.**

This refers to that the genotypes that show high water status, high chlorophyll content and high leaf area can be considered most tolerant to drought than others. But stepwise regression revealed that relative water content was the most important physiological trait followed by flag leaf area under well-watered conditions, while chlorophyll content was the most important physiological trait under drought conditions followed by excised leaf water loss that that contributed high amount of the total variation of grain yield. Selections based on simple correlation coefficients without considering the interactions among yield and the independent attributes may mislead the breeder to reach his main breeding purposes (Del Moral *et al* 2003). Therefore, path coefficient and stepwise regression are more informative than correlation because of separating the direct effects from the indirect effects and determine the variables accounting for the majority of the total yield variation, respectively.

CONCLUSION

It can be concluded that among yield components, panicle weight and threshing percentage were critical for maintaining yields under drought conditions. While chlorophyll content, excised leaf water loss and stay green were the most important physiological traits under drought stress conditions. In addition, these traits showed the highest direct positive effects on grain yield under drought stress, while panicle width and chlorophyll content showed the highest positive indirect effects on grain yield/plant. Therefore, selection can be done under drought stress conditions for these traits as selection criteria for drought tolerance.

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العلاقة بين المحصول وكلاً من مكوناته وبعض الصفات الفسيولوجية في الذرة الرفيعة للحبوب تحت الظروف المروية والجفاف

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أنه من المرغوب فيه لمربي الذرة الرفيعة للحبوب أن يعرف مدي العلاقة بين المحصول والصفات المورفولوجية والفسيولوجية المؤثرة عليه والتي تسهل للمربي انتخاب نباتات ذات صفات مرغوبة خاصة تحت ظروف نقص الماء. ولهذا, أجريَ هذا العمل في منطقتين تمثلان نوعين من التربة تابعتين للمزارع التجريبية لكلية الزراعة جامعة أسيوط بمحافظة اسيوط, مصر, خلال موسمي ٢٠١٤ و ٢٠١٥ تحت الظروف المروية ووظروف الجفاف. لتنفيذ الظروف المروية, فانه استخدم نظام الري السطحي في التربة الطينية ورويت النباتات كل ١٤ يوم بينما استخدم نظام الري بالتنقيط في التربة الرملية حيث رويت النباتات كل ثلاث أيام لمدة ساعتين. وللحصول علي ظروف الجفاف تم منع الرية الثالثة والخامسة في التربة الطينية بينما رويت النباتات كل ثلاث أيام لمدة ساعة واحدة بنظام الري بالتنقيط. أستخدمت ثلاث طرق احصائية هي معامل الارتباط البسيط, تحليل معامل المرور و تحليل الإنحدار المتدرج لتحديد العلاقات بين المحصول ومكوناته وبعض الصفات الفسيولوجية تحت كلاً من المعاملتين. أستخدم لذلك ٤٣ تركيب وراثي من الذرة الرفيعة للحبوب شملت ٣٠ هجيناً وأبائها الأحد عشر (٦ أمهات و٥ أباء تم التهجين فيما بينها بنظام تزاوج السلالة في الكشاف) بالاضافة لصنفين قياسيين هما هجين ٣٠٥ ودورادو. أظهرت النتائج وجود اختلافات عالية المعنوية بين التراكيب الوراثية لكل الصفات المدروسة تحت كلا المعاملتين. أرتبط وزن القنديل ارتباطاً موجباً عالياً مع محصول الحبوب في كلاً من المعاملتين تلاه في قوة الارتباط نسبة التفريط ومعامل البذرة مما يشير إلي أن هذه الصفات هي الأكثر مساهمة في المحصول. كما أشار تحليل معامل المرور أن وزن القنديل ونسبة التفريط كان لهما تأثير مباشر إيجابي علي محصول النبات, بينما كان محتوي الكلوروفيل ونسبة فقد الماء من الورقة المقطوعة و عدد الأوراق الخضراء حتي الحصاد أكثر الصفات الفسيولوجية تأثيراً في صفة المحصول تحت ظروف الجفاف. بالإضافة الي ذلك أن عرض القنديل ومحتوي الكلوروفيل كان لهما تأثيراً عالياً غير مباشر علي محصول الحبوب للنبات تحت ظروف الجفاف. أظهر تحليل الإنحدار المتدرج أن صفتي وزن القنديل ونسبة التفريط أقوي الصفات تأثيراً في تباين صفة المحصول تحت ظروف الجفاف. علي الجانب الأخر, كان هناك ارتباط موجب معنوي بين الصفات الفسيولوجية وصفة المحصول تحت كلاً من المعاملتين (ما عدا صفة فقد الماء من الورقة المقطوعة تحت الظروف المروية). أشار تحليل الانحدار المتدرج أن المحتوي المائي النسبي أكثر الصفات الفسيولوجية تاثراً في تباين صفة المحصول تحت الظروف المروية تلتها صفة مساحة ورقة العلم, بينما محتوي الكلوروفيل الأكثر تأثيراً في التباين الكلي لصفة المحصول تحت ظروف الجفاف تلتها صفة فقد الماء من الورقة المقطوعة.

المجلة المصرية لتربية النبات ٢٠ (٥) :٧٧٣- ٧٩٥ (٢٠١٦)